The Effect of Four-lane to Three-lane Conversion on the Crash Frequencies and Crash Rates on Iowa Roads: A Summary

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As part of a ISU Statistics Dept. creative component in cooperation with Iowa Department of Transportation Office of Traffic and Safety (TAS), a full Bayes analysis of the reduction in crash frequency due to 4-lane to 3-lane conversions in Iowa was conducted. The study utilized monthly crash data and estimated volumes obtained from TAS for 30 sites, 15 treatment (sites 1 through 15) and 15 control (sites 18 through 32), over 23 years (1982-2004). The sites had volumes ranging from 2,030 to 15,350 during that timespan and were largely located in smaller urbanized areas (see Table 1 for full site descriptions).

SID	CITY	LITERAL	CIPOP 2000	ADT 2000
1	Storm Lake	Iowa 7 from Lake Ave. to Lakeshore Dr.	10,076	7,503
2	Clear Lake	US 18 from N 16 st. W to N 8th St.	8,161	10,403
3	Mason City	Iowa 122 from West intersection of Birch Drive to a Driveway	29,172	7,800
4	Osceola	US 34 from Corporate limits on east side to where highway divides to 4 lanes on west side	4,659	8,172
5	Manchester	Iowa 13 from River St. to Butler St.	5,257	9,400
6	Iowa Falls	US 65 from City Limits - ? to Park Ave.	5,193	10,609
7	Rock Rapids	Iowa 9 from S Greene St. to Tama St.	2,573	4,766
8	Glenwood	US 275 from MP 36.2 to MP 37.42	5,358	6,410
9	Des Moines	Beaver Ave from Urbandale Ave. to Aurora Ave.	198,682	13,695
10	Council Bluffs	US 6 from McKenzie Ave. west 1300 ft.	58,268	11,000
11	Blue Grass	Old US 61 from Oak Lane to 400' W of Terrace Drive	1,169	9,155
12	Sioux Center	US 75 from 200' South of 10th St. S. to 250' North of 9th St. NW	6,002	8,942
13	Indianola	Iowa 92 from South R St. to Jct. of US 65/69	12,998	13,288
14	Lawton	US 20 from 100' east of Co. Rd. Eastland Ave. to 1130' West of Co. Rd. Emmet Ave.	697	9,237
15	Sioux City	Transit Ave. from Vine Ave. to just west of Paxton St. at curve	85,013	9,608
18	Storm Lake	Iowa 7 from Lake Ave. to Barton St	10,076	8,790
19	Le Mars	US 75 from 0.01 miles north of 3rd St NW to 0.36 miles SW of 12th St SW	9,237	10,880
20	Cedar Falls	Green Hill Road from 0.10 miles east of IA 58 to 0.09 miles west of Cedar Heights Dr.	36,145	2,768
21	Jefferson	Iowa 4 from National Ave to 0.13 miles north of 250th Ave	4,626	5,685
22	Harlan	Iowa 44 from US 59 to 6th St	5,282	6,981
23	Norwalk	Iowa 28 from 0.03 miles south of Gordon Ave to 0.04 miles south of North Ave	6,884	7,679
24	Belmond	US 69 from 0.38 miles north of Main St to 0.58 miles south of Main St	2,560	3,734
25	Harlan	Iowa 44 from US 59 to 6th St	5,282	6,981
26	Des Moines	Hickman Road - 40th Place east to 0.07 miles west of W 18th St	198,682	13,953
27	Ames	13th Street from 0.09 miles east of Stange Road to 0.07 miles west of Crescent Circle Dr.	50,731	10,711
28	Mapleton	Iowa 141 from 0.02 miles north of Sioux St. to 0.08 miles south of Oak St.	1,322	3,007
29	Algona	US 169 from 0.07 miles south of US 18 to 0.23 miles south of Irvington Rd.	5,741	7,263
30	Oskaloosa	Iowa 92 from 0.12 miles east of IA 432 to 0.07 miles west of Hillcrest Dr	10,938	11,143
31	Merrill	US 75 from 0.05 miles north of 2nd St to 0.18 miles north of Jackson St	754	7,774
32	Sioux City	S. Lakeport from 4th Ave to Lincoln Way	85,013	15,333

Table 1: Site locations

Each treatment site had different known intervention dates (see Table 2); therefore, the number of before and after crash records varied from site to site. Individual control sites were matched to each treatment site to provide a control sample similar to the treatment sample; these matches are shown in Table 2 using columns SID (the site ID) and YID (the paired ID).

SID	YID	ROUTE	LANES	LENGTH	COMPYEAR
1	18	IA 7	3	1.41	1993
2	19	US 18	3	1.51	2003
3	20	IA 122	3	1.78	2001
4	21	US 34	3	2.04	2001
5	22	IA 13	3	0.35	2001
6	23	US 65	3	1.23	2002
7	24	IA 9	3	0.35	1998
8	25	US 275	3	1.09	1998
9	26	Local	3	1.19	1999
10	27	US 6	3	0.20	2000
11	28	Local	3	0.72	1999
12	29	US 75	3	1.52	1999
13	30	IA 92	3	1.57	1999
14	31	US 20	3	0.64	2000
15	32	Local	3	0.77	2000
18	1	IA 7	4	0.71	1993
19	2	US 75	4	1.80	2003
20	3	Local	4	1.80	2001
21	4	IA 4	4	2.40	2001
22	5&8	IA 44	4	1.20	2001
23	6	IA 28	4	0.80	2002
24	7	US 69	4	0.90	1998
25	5&8	IA 44	4	1.20	1998
26	9	Local	4	1.50	1999
27	10	Local	4	0.33	2000
28	11	IA 141	4	0.70	1999
29	12	US 169	4	2.00	1999
30	13	IA 92	4	1.50	1999
31	14	US 75	4	0.50	2000
32	15	Local	4	1.20	2000

Table 2: Site descriptive information

In general, both treatment and control site crash history can be seen to experience a reduction. However, the reduction in treatment site crash frequency and rate after intervention are significantly more marked than at the comparison sites (see Figures 1 and 2, where the vertical bar represents the intervention date for the treatment site). This differs from a previous 4-lane to 3-lane study (Huang, et al. 2002, HSIS 2004, HSIS 2005), recently published in ITE Journal, whose data, even from a descriptive statistics standpoint, indicated very little reduction or difference between the two groups. Additionally, because monthly crash frequencies were used for analysis, it was possible to account for the seasonality effects on crashes, which should be expected given the seasonal weather patterns in Iowa.
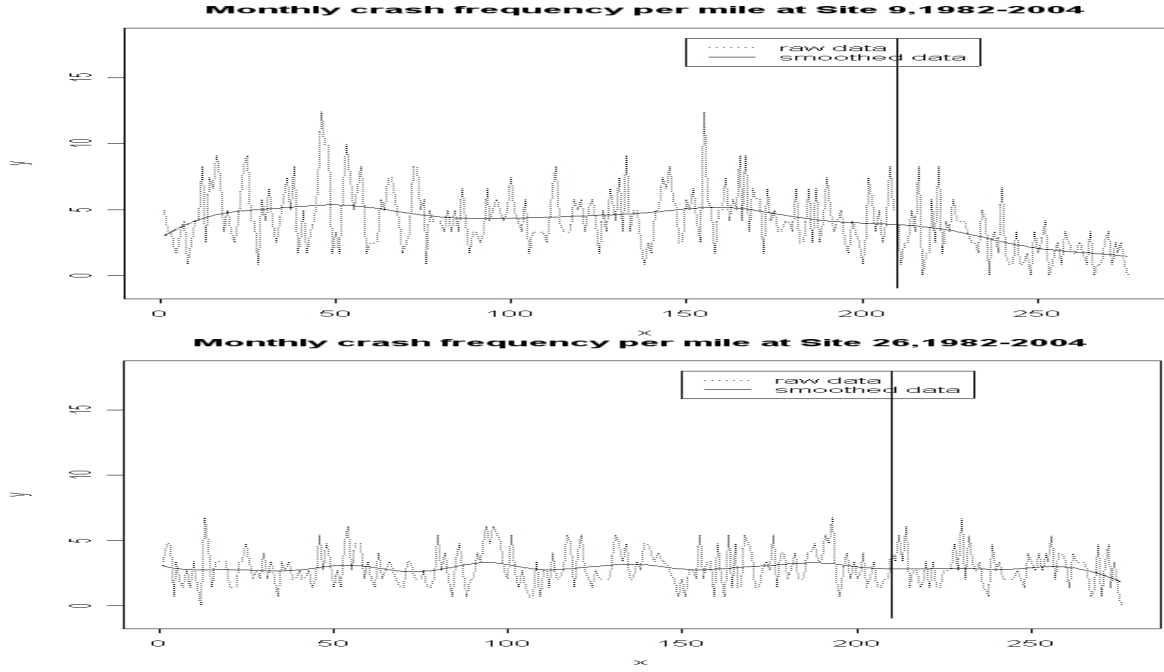
Figure 1: Observed and smoothed estimated monthly crash density for a sample pair of sites
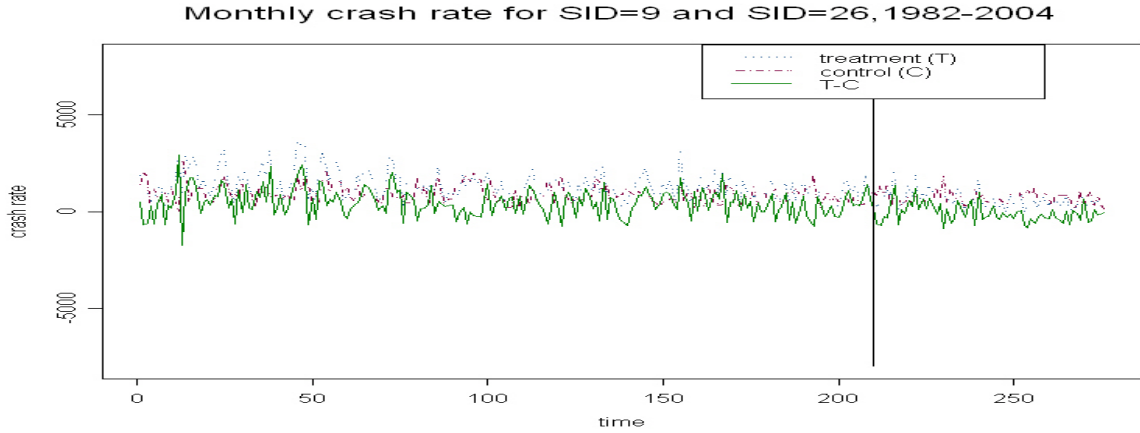

Figure 2: Monthly crash rate at and difference in monthly crash rate for a sample pair of sites

Given the random and rare nature of crash events, a hierarchical Poisson model where the log mean was expressed as a function of time period, seasonal effects, and a random effect corresponding to each site included was fitted to the crash frequencies. To formulate the model, first notation is defined. In the following:

i denotes site and takes on values 1 to 30,

t denotes month (or time period) and takes on values 1 to 276 (for i=17, t is from 1 to 252),

y_{it} denotes the number of monthly crashes at site i during time period (month) t,

v_{it} is the estimated monthly average daily traffic (MADT) for site i at time period t,

id_i is a random effect corresponding to site i,

t_{0i} denotes the time period during which the intervention is completed for treated site i and (fictitiously) for the corresponding matched site

$$X_{1it} := \begin{cases} 1, \text{if site } i \text{ is treated at some time} \\ 0, \text{if site } i \text{ is in control group} \end{cases},$$

$$S_{it} := \begin{cases} 1, \text{if t belongs to Winter (December, January, and February)} \\ 2, \text{if t belongs to Spring (March, April, and May)} \\ 3, \text{if t belongs to Summer (June, July, and August)} \\ 4, \text{if t belongs to Fall (September, October and November)} \end{cases},$$

and, $X_{2it} = \cos\left(\dfrac{2\pi \times S_{it}}{4}\right)$, $X_{3it} = \cos\left(\dfrac{4\pi \times S_{it}}{4}\right)$, $X_{4it} = \sin\left(\dfrac{2\pi \times S_{it}}{4}\right)$.

We postulate that the number of monthly crashes at a site y_{it} is a Poisson random variable with mean $\lambda_{it} v_{it}$, and divided by 1,000 just for numerical convenience. Then,

$$y_{it} \sim Poi\left(\frac{\lambda_{it} v_{it}}{1000}\right).$$

At the second level, we model the log crash rate as a piecewise linear function of the covariates defined above, such that the function is continuous at the change point. The model is

$$\log(\lambda_{it}) = \beta_1 + \beta_2 X_{1it} + \beta_3 t + \beta_4 (t - t_{0i}) I_{(t>t_{0i})} + \beta_5 X_{1t} t + \beta_6 X_{1t} (t - t_{0i}) I_{(t>t_{0i})}$$
$$+ \beta_7 X_{2it} + \beta_8 X_{3it} + \beta_9 X_{4it} + id_i$$

where

$$id_i \sim N\left(0, \left(\tau_{bw}^2\right)^{-1}\right), \quad I_{(t>t_{0i})} = \begin{cases} 1, \text{if } t > t_{0i} \\ 0, \text{if } t \leq t_{0i} \end{cases},$$

and τ_{bw}^2 is the between-site precision, defined as the inverse of the between-site variance in monthly number of crashes.

A full Bayesian (FB) approach (Gelman, A., et al., 2004, and Pawlovich, 2003) was adopted for estimation of model parameters. In the Bayesian approach, model parameters are treated as random variables and the goal is to estimate the distribution of likely values of the parameters given prior and data information. The approach differs from classical methods in that distributions of likely values, rather than point estimates and standard errors of parameters are obtained, and in that all results are conditional on the sample at hand. The empirical Bayes (EB) approach (Hauer, 1997) is a variant in which prior distributions are partially based on the sample.

Results indicate a 25.2% (23.2% - 27.8%) reduction in crash frequency per mile and an 18.8% (17.9% - 20.0%) reduction in crash rate. This differs again from the Huang study (Huang, et al. 2002, HSIS 2004, HSIS 2005) which reported a 6% reduction in crash frequency per mile and an insignificant indication for crash rate effects. This difference is evident just by comparing the

raw data from the two studies. The Iowa data, when graphed, indicates marked reductions whereas the Huang data indicate very little difference. Based on these Iowa FB results and results from a simple before/after analysis done as part of a separate causal study, we are comfortable with the 25% and 19% reductions, especially as they fit practitioner expectations. Other benefits shown from a previous internal Iowa study on speeds, travel times, and delays on the Sioux Center conversion during AM and PM peak periods, indicate a 4-5 mph reduction in 85th percentile free flow speed and a 12-14% reduction in percentage of vehicles traveling more than 5 mph over the speed limit (i.e., vehicles traveling 35 mph or higher).

The differences between our analysis and the analysis performed by Huang (Huang, et al. 2002, HSIS 2004, HSIS 2005) are several and may explain the diverging results. First, even the descriptive analysis of the "raw" data suggests that the effect of conversion in Iowa roads was much more dramatic than in the roads considered in the Huang study. See, for example, the descriptive statistics presented in Table 3 of this report. Second, Huang fitted an ordinary linear regression model to the expected crash frequencies, meaning that a single slope for expected frequency on time was assumed for the entire study period. We extended the model and allowed for different slopes during the "before" and the "after" periods explicitly by including a change-point in the model and for the interaction of treatment and slope. Notice that as a result, our model allows for a slight increase in crash frequency during the months immediately preceding the conversion and also during those months immediately following the conversion. Finally, we included a longer time series of crash frequencies as we included 23 years of data on almost all sites in the study. By analyzing monthly data, we were also able to account for seasonal variability in crash frequency and traffic volume; while a "must" in Iowa, where seasonal variation in driving conditions is marked, this may not be as critical in a study conducted in the northwestern region of the country. Huang's study, though it began with 12 treatment sites and 25 control sites was reduced to 8 treatment sites and 14 control sites due to unavailability of data. Additionally, Huang utilized only 3 years of data for both the before and after period.

References

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